[redacted]

ZOOM LENS HAVING AN ANTI-VIBRATION FUNCTION

The present invention relates to anti-vibration technology for a photographic lens, a video zoom lens, etc. More specifically, it relates to a long focal length zoom lens having an anti-vibration function.

BACKGROUND OF THE INVENTION

An example of a zoom lens having an anti-vibration function is disclosed in Japanese Patent Kokai H1-191113. This zoom lens comprises more than two lens groups, which corrects vibration by moving the lens group or a part of the lens groups during zooming.

However, in the above conventional technology, the focal length at the telephoto end is so short that it is not suitable for a zoom lens with a long focal length. Also, the zoom lens of conventional technology does not provide sufficient back focusing for a single-lens reflex camera or electronic imaging equipment.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to overcome the problems of the prior art.

Another object of the present invention is to provide a zoom lens capable of being applied to a single-lens reflex camera and which is suited to a zoom lens applicable to high-resolution photography or electronic imaging equipment. Such equipment can have a long focal length.

The apparatus incorporating the principles of the present invention solves the problems by providing a zoom lens having, in order from the object end: a first lens group G_1, a second lens group G_2 having a negative refractive power, and a last lens group G_L arranged closest to the image end of the zoom lens. The first lens group G_1 includes a focusing lens group G_{1N}, and the last lens group G_L includes an anti-vibration lens group G_V. In addition, the focusing lens group G_{1N} moves along the direction of the optical axis of the zoom lens during focusing, at least the second lens group G_2 moves along the direction of the optical axis during zooming, and the anti-vibration lens group G_V moves in a direction substantially perpendicular to the optical axis during vibration correction.

The apparatus incorporating the principles of the present invention is suitable for a photographic or video zoom lens in that it employs the technique in which the zoom lens is arranged basically, in order from the object end: a first lens group G_1 having a positive refractive power, a second lens group G_2 having a negative refractive power, and a last lens group G_L having a positive refractive power and arranged closest to the image end of the zoom lens, wherein at least the second lens group G_2 is moved toward the image end during zooming from the wide-angle end to the telephoto end.

In addition, an object at an intermediate distance is focused by moving on the optical axis a negative lens group G_{1N} , which is a part of the first lens group G_1.

Also, it is preferable that a third lens group G_3 having a positive refractive power is arranged between the second lens group G_2 and the last lens group G_L. This configuration provides higher magnification power and higher performance.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features, and advantages of the present invention will become more apparent from the following detailed description taken with the accompanying drawings, in which:

Figure 1 is a lens layout of Embodiment 1 of the present invention;

Figure 2 is a diagram showing various aberrations at the wide-angle end of Embodiment 1;

Figure 3 is a diagram showing various aberrations at the telephoto end of Embodiment 1;

Figure 4 is a lens layout of Embodiment 2 of the present invention;

Figure 5 is a diagram showing various aberrations at the wide-angle end of Embodiment 2;

Figure 6 is a diagram showing various aberrations at the telephoto end of Embodiment 2;

Figure 7 is a lens layout of Embodiment 3 of the present invention;

Figure 8 is a diagram showing various aberrations at the wide-angle end of Embodiment 3; and

Figure 9 is a diagram showing various aberrations at the tele-photo end of Embodiment 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The anti-vibration technique of the zoom lens incorporating the principles of the present invention is described herein. A technique is used in which a lens group or a part of the lens group is moved in a direction substantially perpendicular to the optical axis using an anti-vibration displacement means. This corrects the imaging fluctuation caused by camera shaking or vibration. As a result, the anti-vibration function has an effect of image-stabilization.

Characteristics and advantages of this type of zoom lens will be described. First, it provides a long focal length zoom lens. Second, it provides excellent image performance at each of the focal lengths. For example, for a photographic zoom lens, a lens, which can be as short as 150 mm at the short focal point end and as long as 500 mm at the long focal point end, is popular.

Because of this excellent property, this type of zoom lens is widely used as a photographic or video long focal length zoom lens. When a lens focuses by means of the first lens group G_1, which is closest to the object end, the amount of movement of the focusing group G_{IN} with respect to an object at a predetermined distance becomes constant regardless of the zoom

position. Thus, the focusing mechanism can be advantageously simple. This configuration keeps aberration fluctuation small during focusing, which is also favorable.

In a zoom lens in which a convex lens group is closest to the object end of the zoom lens, the first lens group is generally large. Using the first lens group G_1 or a part of it as an anti-vibration corrective optical system, which moves in the direction substantially perpendicular to the optical axis, will unfavorably increase the size of the holding mechanism and the driving mechanism.

Similarly, the first lens group G_1 in the apparatus incorporating the principles of the present invention should not be used for vibration correction to avoid having focusing within the mechanism. Also, the second lens group G2 and the third lens group G3, which moves along the optical axis during zooming should not be used for vibration correction.

The apparatus incorporating the principles of the present invention avoids the problems mentioned above and provides excellence in aberration correction properties during anti-vibration by forming an anti-vibration lens group G_V within the last lens group G_L. That is, the lens group G_L is the lens group closest to the image end of the lens system. In this case, it is desirable that an aperture stop be formed in the vicinity of the anti-vibration lens group G_V because this configuration performs anti-vibration without creating an uneven resolution between the center and circumference of the display.

A preferable mode of the present invention is described herein. Figures 1, 4, and 7, respectively, show lens layouts of the zoom lens of Embodiment 1, 2, and 3 of the present invention. In the zoom lens of each of the embodiments, the principles of the present invention are applied to an upper telephoto zoom lens having a very long focal length.

Referring to Figure 1, the zoom lens of Embodiment 1 comprises, in order from the object end:

a first lens group G_1,

a second lens group G_2 having a negative refractive power, and

a last lens group G_L.

As can be seen in Figures 4 and 7, respectively, the zoom lens of Embodiments 2 and 3 each comprise, in order from the object end:

a first lens group G_1,

a second lens group G_2 having a negative refractive power,

a third lens group G_3 having a positive refractive power, and

a last lens group G_L.

In each of the embodiments, the first lens group G_1 comprises, in order from the object side:

a convex lens group G_{11},

a focusing lens group or subgroup G_{1N} having a negative refractive power, and

a convex lens group G_{12}.

The last lens group G_L includes an anti-vibration lens group G_V.

In each of the embodiments, focusing is performed by moving the focusing lens group G_{1N} in the optical axial direction and vibration is corrected by moving the anti-vibration lens group G_V in a direction substantially perpendicular to the optical axis. In Embodiment 1 (Figure 1), zooming is performed by moving the second lens group G_2 and the last lens group G_L in the optical axial direction. In Embodiments 2 and 3 (Figures 4 and 7), zooming is performed by moving the second lens group G_2 and the third lens group G_3 in the optical axial direction.

It is desirable in all of the embodiments of the present invention that, during zooming from the wide-angle end to the telephoto end, the distance between the first lens group G_1 and the second lens group G_2 be increased and the distance between the second lens group G_2 and the lens group G_L be changed.

It is also desirable that a fixed stop be formed on the optical axis separate from the aperture stop. This will effectively shield unwanted flare beams that may be generated when the anti-vibration lens group G_V is being displaced.

It is also desirable in the apparatus incorporating the principles of the present invention that each of the following conditions (1) through (3) be fulfilled:

$$\Delta S \,/\, |\, f_L \,| < 0.1 \qquad (1)$$

$$0.2 < |\, f_V \,| \,/\, f_L < 10 \qquad (2)$$

$$0.05 < | f_{1N} | / f_1 < 10 \qquad (3)$$

where:

ΔS is the maximum displacement, in the direction substantially perpendicular to the optical axis, of the anti-vibration lens group G_V which moves during the anti-vibration mode;

f_L is the focal length of the last lens group G_L;

f_V is the focal length of the anti-vibration lens group G_V;

f_{1N} is the focal length of the focusing lens group G_{1N}; and

f_1 is the focal length of the first lens group G_1.

Condition (1) defines an appropriate range for the ratio of the maximum displacement amount of the lens group G_V in the direction perpendicular to the optical axis to the focal length f_L of the last lens group G_L. If the upper limit of condition (1) is exceeded, the maximum displacement amount, ΔS, of the anti-vibration lens group G_V becomes too large. As a result, the aberration displacement amount during anti-vibration motion unfavorably increases. Especially, the deviation measured at a peripheral position on the image plane of the meridional direction from that of the sagittal direction unfavorably increases. In addition, such condition suggests an unfavorably complex mechanism. Needless to say, the lens group G_V must move to correct vibration, therefore, ΔS is greater than 0 ($\Delta S > 0$). A better result can be obtained when the upper limit of condition (1) is 0.05.

Condition (2) defines an appropriate range for the ratio of the focal length f_V of the anti-vibration lens group G_V to the focal length f_L of the

last lens group G_L. If the upper limit of condition (2) is exceeded, the focal length f_V of the anti-vibration lens group G_V becomes too large. This may result in diffusing the light beam when it moves in the direction perpendicular to the optical axis. To capture the beam, the anti-vibration lens group G_V will require lenses of an undesirably large diameter. This will increase the size of the entire zoom lens unfavorably.

If the lower limit of condition (2) is exceeded, the focal length f_V of the anti-vibration lens group G_V becomes too short. A spherical aberration tends to move excessively toward the negative side, which is unfavorable.

Also, the amount of movement of an image during the anti-vibration motion becomes too large. This makes the microscopic control, for aligning the anti-vibration lens group G_V required for correcting vibration, difficult. A better result can be obtained when the lower limit of condition (2) is 0.8 and the upper limit is 4.0.

The focal length f_V of the anti-vibration lens group G_V may be positive or negative. If one intends to configure a brighter optical system, the positive f_V is preferable. In this case, condition (2) is expressed as the following condition (2P):

$$0.2 < f_V / f_L < 10 \qquad \text{(2P)}$$

It is also preferable that the anti-vibration lens group G_V has a convex lens at its end closest to the object and has at least one concave lens.

If the focal length, f_V, of the anti-vibration lens group G_V is negative, it is easy to make a compact anti-vibration lens group G_V and to

decrease the length of the entire zoom lens. A preferable result can be obtained for condition (2P) also if the lower limit is 0.8 and the upper limit is 4.0.

Condition (3) defines the refractive power ratio of the focal length f_{1N} of the focusing lens group G_{1N} having a negative refractive power to the focal length f_1 of the first lens group G_1. This condition is important when one intends to obtain an excellent imaging performance when focused. If the upper limit of condition (3) is exceeded, spherical aberration tends to move excessively toward the negative side and the length of the entire lens system undesirably increases. These properties are not suited to a compact zoom lens. In addition, the Petzval sum tends to move excessively toward the positive side, and also, astigmatism and image plane curvature increases, thus providing poor imaging performance.

If the lower limit of condition (3) is exceeded, back focal length will be insufficient, which is unfavorable. Also, spherical aberration moves excessively toward the negative side. This tends to generate outgoing coma aberration among beams above the primary beam, which is unfavorable. A better result can be obtained if the lower limit of condition (3) is 0.1 and the upper limit is 1.0.

It is also desirable to fulfill the following conditions (4) and (5) in order to obtain an even better imaging performance.

$$0.3 < | r_{VL} / f_V | < 30.0 \quad (4)$$

$$0.02 < L / f_L < 0.35 \quad (5)$$

where:

r_{VL} is the radius of curvature of the plane which is at the end of the anti-vibration lens group G_V closest to the image plane; and

L is the thickness of the anti-vibration lens group G_V on the optical axis.

Exceeding either the upper limit or the lower limit of condition (4) is not preferable because spherical aberration, image plane curvature, and astigmatism will fluctuate excessively during anti-vibration motion. A better result can be obtained if the lower limit of condition (4) is 0.4 and the upper limit is 20.0.

Condition (5) defines an appropriate range of the ratio of the thickness of the anti-vibration lens group G_V on the optical axis to the focal length f_L of the last lens group G_L. If the upper limit of condition (5) is exceeded, the thickness L of the anti-vibration lens group G_V becomes too large. This increases the size of the lens group G_V to a great extent, making an unfavorably long zoom lens. This also complicates the anti-vibration mechanism, which is also unfavorable. A better result can be obtained if the lower limit is 0.03 and the upper limit is 0.15.

It is also desirable that the following conditions (6) and (7) be fulfilled in addition to the above-mentioned various conditions when actually configuring the anti-vibration lens group G_V.

$$0.06 < \Delta n \qquad (6)$$

$$5.0 < \Delta \nu \qquad (7)$$

where:

Δn is the difference in the index of refraction between the convex lens in the anti-vibration lens group G_V which is closest to the object end of the zoom lens and the concave lens which is closest to the object end of the zoom lens; and

$\Delta\nu$ is the difference in Abbe number between the convex lens in the anti-vibration lens group G_V which is closest to the object end of the zoom lens and the concave lens which is closest to the object end of the zoom lens.

If the lower limit of condition (6) is exceeded, the spherical aberration at the telephoto end of the zoom lens system becomes difficult to correct, providing poor imaging performance. In this case, the index of refraction of the concave lens which is closest to the object end of the zoom lens is higher than that of the convex lens which is closest to the object end of the zoom lens.

If the lower limit of condition (7) is exceeded, too much chromatic aberration is generated on the axis, providing poor image performance.

For the second lens group G_2 and the third lens group G_3 which constitute the zooming system in the zoom lens configuration, the following conditions are important:

$$0.1 < | f_2 | / f_1 < 0.45 \tag{8}$$

$$0.8 < f_L / f_3 < 1.7 \tag{9}$$

where:

f_2 is the focal length of the second lens group G_2; and

f_3 is the focal length of the third lens group G_3.

If the upper limit of condition (8) is exceeded, not only does the spherical aberration become too large in the negative direction at the telephoto end, but also the coma aberration deviates too much. If the lower limit of condition (8) is exceeded, the astigmatism becomes large; distortion shifts largely to the negative side at the wide-angle end and the telephoto end; and the Petzval sum tends to be too large at the negative side; all of which are unfavorable.

If the upper limit of condition (9) is exceeded, the spherical aberration becomes extremely large in the negative direction, and the coma aberration fluctuates too much; both of which are unfavorable.

If the lower limit of condition (9) is exceeded, the length of the entire zoom lens becomes too long, which is unfavorable. The distortion becomes too large in the positive direction at the telephoto end, which is undesirable. In addition, the lens group at the object end will use lenses of a larger diameter than that of the third lens group G_3, which is also unfavorable.

It is desirable that the first lens group G_1 has a convex lens group G_{11} toward the object end from the negative focusing lens group G_{1N} and that the following condition be fulfilled:

$$0.15 < L_{1N} / f_1 < 0.8 \qquad (10)$$

where:

L_{1N} is the distance between the convex lens group G_{11} and the focusing lens group G_{1N} when focused at an infinitely far object distance.

If the upper limit of condition (10) is exceeded, the length of the entire first lens group G_1 becomes too long, which is unfavorable. Also, the Petzval sum tends to move toward the positive side, which is also unfavorable. If the lower limit of condition (10) is exceeded, not only does the diameter of the focusing lens group G_{1N} become too large, but also a larger diameter is required for the lens group closer to the image end than the focusing lens group G_{1N}, which is unfavorable as well.

In addition, it is desirable that the first lens group G_1 has a convex lens group G_{12} at the image end of the focusing lens group G_{1N}. This configuration allows the focusing lens group G_{1N} to have more freedom of dividing refractive power internally, helping the first lens group G_1 to provide excellent focusing performance.

It is also desirable that the following condition be fulfilled:

$$0.2 < f_1 / (f_W \cdot Z) < 0.8 \quad (11)$$

where:

f_W is the focal length of the overall zoom lens at the wide-angle end; and

Z is a zoom ratio of the overall zoom lens.

If the upper limit of condition (11) is exceeded, the focal length f_1 of the first lens group G_1 becomes too large. This makes the length of the entire zoom lens too large. Also, the lens group at the image end will use lenses of a larger diameter than that of the second lens group G_2, which is also unfavorable.

If the lower limit of condition (11) is exceeded, the focal length f_1 of the first lens group G_1 becomes too small and coma aberration fluctuates too much, which is unfavorable. The Petzval sum tends to move excessively toward the positive side, which is also unfavorable.

The zoom lens of the type described above is suited to a long focal length zoom lens. It is desirable that it fulfill the following conditions:

$$f_t / L_A > 7.0 \qquad (12)$$

$$f_W / L_A > 3.5 \qquad (13)$$

where:

f_t is the focal length of the overall zoom lens at the telephoto end; and

L_A is the diagonal length of the field of view.

If conditions (11) and (12) are not fulfilled, the purpose of the apparatus incorporating the principles of the present invention will not best be served and various aberrations will not be corrected accurately. Especially image plane curvature and coma aberration will be difficult to correct.

When configuring a zoom lens in reality, it is desirable, in addition to fulfilling the above conditions, that the first lens group G_1 and the last lens group G_L are fixed such that zooming is performed by moving the second lens group G_2 and the third lens group G_3 or the second lens group G_2 and the last lens group G_L. Also, when arranging the third lens group G_3, it is desirable that the space between the third lens group G_3 and the last lens group G_L is made afocal. This configuration will provide a simple zooming mechanism.

The shape of each of the lens groups which permits the lens groups to constitute the zoom lens is described herein. In the last lens group G_L, it is desirable that the anti-vibration lens group G_V be located at the end of the last lens group G_L closest to the image end of the zoom lens or G_V be located at the image end of the convex lens group. If the convex lens group is located at the image end, it converges light thereon, requiring a smaller diameter for the lens used for the anti-vibration lens group G_V. If the overall length of the last lens group G_L or the diameter of the lenses can be small, the overall last lens group G_L can be used as an anti-vibration lens group G_V.

When constructing the anti-vibration lens group G_V with two lenses to have a positive refractive power, it is desirable to use a biconvex lens and a concave meniscus lens which has a strong concave surface facing toward the object end.

When constructing the anti-vibration lens group G_V with three lenses to have a positive refractive power, it is desirable to use a biconvex lens, a biconcave lens, and a convex lens.

When constructing the anti-vibration lens group G_V with two lenses to have a negative refractive power, it is desirable to use at least one biconcave lens and at least one convex lens.

If a refractive power distribution type lens or an aspherical surface lens is used in any of the lens groups which constitute an embodiment of the zoom lens of the present invention, a better imaging performance or anti-vibration performance can be obtained.

In the apparatus incorporating the principles of the present invention, the technique in which the anti-vibration lens group G_V is moved in the direction substantially perpendicular to the optical axis is used. However, the anti-vibration lens group G_V can be rotated around the optical axis or a given point near the optical axis. In other words, by adding a tilted component to the shift component in the anti-vibration motion, a better anti-vibration optical performance can be obtained. In addition, it is also possible to correct vibration by eccentrically driving a part of the lens group in the anti-vibration lens group G_V.

The following Table 1 through Table 3 show basic data on Embodiments 1 through 3. Under "Various Lens Values," No. is the number of each lens surface from the object side, r is the radius of curvature for each lens surface, d is the separation of each lens surface, ν_d is the reference Abbe number for each lens at the d-line (λ = 587.6 nm), and n_d and n_g, respectively, are the refractive index of each lens at the d-line and g-line (λ = 435.8 nm). The seventh column shows the group number to which each of the lens belongs. In the "anti-vibration data," the direction in which the anti-vibration lens group G_V and an image move is positive in the upper level of the optical path diagram.

Table 4 shows various values related to each of the conditions (1) through (13) as mentioned and values for each of the conditions (1) through (13).

Table 1

Variable Lens Values

No.	r	d	ν_d	n_d	n_g	
1.	662.5300	15.5000	82.52	1.497820	1.505265	G_{11}
2.	−1317.3200	2.0000				
3.	366.1710	27.0000	82.52	1.497820	1.505265	G_{11}
4.	−595.5800	8.2000				
5.	−550.7400	7.0000	35.19	1.749501	1.776948	G_{11}
6.	936.3600	0.3000				
7.	269.9760	19.0000	82.52	1.497820	1.505265	G_{11}
8.	4433.9970	(d_8)				
9.	−721.9200	4.5000	25.50	1.804581	1.846310	G_{1N}
10.	−331.9570	3.8000	55.60	1.696800	1.712319	G_{1N}
11.	147.0490	9.0000				
12.	−708.3800	9.8000	25.50	1.804581	1.846310	G_{1N}
13.	−93.4900	2.8000	40.90	1.796310	1.821068	G_{1N}
14.	574.5604	(d_{14})				
15.	2151.5997	4.2000	35.19	1.749501	1.776948	G_{12}
16.	279.0760	11.6000	82.52	1.497820	1.505265	G_{12}
17.	−133.6300	(d_{17})				
18.	145.2250	7.3000	28.19	1.740000	1.774461	G_2
19.	−190.6860	2.9000	51.09	1.733500	1.751403	G_2
20.	103.6120	7.0000				
21.	−165.4190	3.7000	45.37	1.796681	1.818801	G_2
22.	338.4810	0.1000				
23.	88.7090	4.0000	32.17	1.672700	1.699894	G_2
24.	91.6570	(d_{24})				
25.	107.8234	8.9000	60.03	1.640000	1.653133	G_L
26.	−1108.1819	4.0000	40.90	1.796310	1.821068	G_L

27.	108.4408	5.0000					
28.	195.2262	8.1000	70.41	1.487490	1.495932	G_L	
29.	−183.0491	3.0000					
30.	364.4336	5.7000	70.41	1.487490	1.495932	G_L	G_V
31.	−492.4989	4.0000					
32.	−220.0000	1.0000	35.51	1.595071	1.616844	G_L	G_V
33.	263.8906	2.0000					
34.	224.0339	5.7000	37.90	1.723421	1.748045	G_L	G_V
35.	−427.9968	(d_{35})					
36.	(Aperture Stop)	87.7401					
37.	(Fixed Stop)	93.5094					
38.	∞	2.0000	64.10	1.516800	1.526703		
39.	∞	119.7163					

Variable Lens Separation Values

	Wide-Angle End	Telephoto End
d_8	174.55565	174.55565
d_{14}	16.15305	16.15305
d_{17}	84.61909	99.46369
d_{24}	53.41727	1.58577
d_{35}	25.68265	62.66245

Anti-Vibration Data

Movement amount of the anti-vibration lens group		G_V: $\Delta S = +5$
Movement amount of the image	Wide-Angle End:	+3.970
	Telephoto End:	+4.395

Table 2

Various Lens Values

No.	r	d	ν_d	n_d	n_g	
1.	308.9479	12.0000	82.52	1.497820	1.505260	G_{11}
2.	-789.7229	0.5000				
3.	138.1325	5.6000	31.62	1.756920	1.787940	G_{11}
4.	94.2767	20.0000	82.52	1.497820	1.565260	G_{11}
5.	538.8153	(d_5)				
6.	-2329.7471	3.5000	53.93	1.713000	1.729410	G_{1N}
7.	163.1848	5.0000				
8.	-400.1187	3.5000	49.52	1.744430	1.763210	G_{1N}
9.	142.8639	1.5000				
10.	147.9907	6.7000	31.08	1.688930	1.717750	G_{1N}
11.	-903.7688	(d_{11})				
12.	234.0780	5.5000	60.14	1.620410	1.633140	G_{12}
13.	-708.1720	0.2000				
14.	186.2251	3.6000	27.61	1.755200	1.791120	G_{12}
15.	125.5000	7.2000	82.52	1.497820	1.505260	G_{12}
16.	-452.3328	(d_{16})				
17.	7497.9146	2.1000	58.50	1.651600	1.665380	G_2
18.	70.7008	5.0000				
19.	-75.6345	2.3000	53.93	1.713000	1.729410	G_2
20.	65.0000	4.0000	23.01	1.860740	1.910650	G_2
21.	332.1910	(d_{21})				
22.	182.5239	7.2000	58.54	1.612720	1.625690	G_3
23.	-50.2000	2.4000	31.62	1.756920	1.787940	G_3
24.	-130.1925	(d_{24})				
25.	(Aperture Stop)	0.5000				
26.	112.9942	4.6000	82.52	1.497820	1.505260	G_L

27.	245.8845	2.0000					
28.	158.9831	3.0000	54.55	1.514540	1.526319	G_L	G_V
29.	477.1798	4.8000					
30.	300.0000	3.0000	38.03	1.603420	1.623810	G_L	G_V
31.	118.8950	4.0000					
32.	150.8241	4.0000	47.07	1.670030	1.688063	G_L	G_V
33.	-4987.1629	3.0000					
34.	(Fixed Stop)	34.6000					
35.	153.6804	4.7000	53.48	1.547390	1.560219	G_L	
36.	42.5831	2.0000					
37.	50.1508	1.8000	45.37	1.796680	1.818790	G_L	
38.	47.4766	5.5000	69.98	1.518601	1.527667	G_L	
39.	152.6898	131.3130					

Variable Lens Separation Values

	Wide-Angle End	Telephoto End
d_5	68.43775	68.43775
d_{11}	26.85652	26.85652
d_{16}	4.68513	50.91943
d_{21}	75.62639	1.23629
d_{24}	10.00216	38.15796

Anti-Vibration Data

Movement amount of the anti-vibration lens group		G_V: $\Delta S = +2$
Movement amount of the image	Wide-Angle End:	-1.404
	Telephoto End:	-1.404

Table 3

Various Lens Values

No.	r	d	ν_d	n_d	n_g	
1.	308.9479	12.0000	82.52	1.497820	1.505260	G_{11}
2.	-789.7229	0.5000				
3.	138.1325	5.6000	31.62	1.756920	1.787940	G_{11}
4.	94.2767	20.0000	82.52	1.497820	1.505260	G_{11}
5.	538.8153	(d_5)				
6.	-2329.7471	3.5000	53.93	1.713000	1.729410	G_{1N}
7.	163.1848	5.0000				
8.	-400.1187	3.5000	49.52	1.744430	1.763210	G_{1N}
9.	142.8639	1.5000				
10.	147.9907	6.7000	31.08	1.688930	1.717750	G_{1N}
11.	-903.7688	(d_{11})				
12.	234.0780	5.5000	60.14	1.620410	1.633140	G_{12}
13.	-708.1720	0.2000				
14.	186.2251	3.6000	27.61	1.755200	1.791120	G_{12}
15.	125.5000	7.2000	82.52	1.497820	1.505260	G_{12}
16.	-452.3328	(d_{16})				
17.	7497.9146	2.1000	58.50	1.651600	1.665380	G_2
18.	70.7008	5.0000				
19.	-75.6345	2.3000	53.93	1.713000	1.729410	G_2
20.	65.0000	4.0000	23.01	1.860740	1.910650	G_2
21.	332.1910	(d_{21})				
22.	182.5239	7.2000	58.54	1.612720	1.625690	G_3
23.	-50.2000	2.4000	31.62	1.756920	1.787940	G_3
24.	-130.1925	(d_{24})				
25.	(Aperture Stop)	0.5000				
26.	101.9817	4.6000	82.52	1.497820	1.505260	G_L

27.	393.7533	2.0000				
28.	275.7897	3.0000	32.17	1.672700	1.699894	G_L G_V
29.	784.8842	2.0000				
30.	700.0000	3.0000	39.82	1.869940	1.897730	G_L G_V
31.	142.7415	4.0000				
32.	130.8911	4.0000	47.07	1.670030	1.688063	G_L
33.	2674.1894	3.0000				
34.	(Fixed Stop)	34.6000				
35.	156.4656	4.7000	64.10	1.516800	1.526703	G_L
36.	−129.8808	7.8415				
37.	−95.5445	1.8000	49.45	1.772789	1.792324	G_L
38.	50.1655	5.5000	54.55	1.514540	1.526319	G_L
39.	−139.3284	115.8756				

Variable Lens Separation Values

	Wide-Angle End	Telephoto End
d_5	68.43775	68.43775
d_{11}	26.85652	26.85652
d_{16}	4.68513	50.91943
d_{21}	75.62639	1.23629
d_{24}	14.49508	42.65088

Anti-Vibration Data

Movement amount of the anti-vibration lens group G_V: $\Delta S = +1.5$

Movement amount of the image Wide-Angle End: +0.896

Telephoto End: +0.896

Table 4

Embodiment Number		1	2	3
ΔS		5.0	2.0	1.5
f_L		171.689	225.000	225.000
f_V		433.887	272.470	-312.334
f_{1N}		-122.298	-160.000	-160.000
f_1		895.485	235.000	235.000
f_2		-116.401	-51.500	-51.500
f_3		—	160.000	160.000
r_{VL}		-427.997	-4987.1629	142.7415
L		18.4	18.8	8.0
Z		1.417	3.000	3.000
L_{1N}		174.556	68.438	68.438
f_W		1200.15	200.000	200.000
f_T		1699.706	599.998	599.998
L_A		43.2	43.2	43.2
(1)	$\Delta S / \mid f_L \mid$	0.0291	0.00889	0.00667
(2)	$\mid f_V \mid / f_L$	2.527	1.211	1.388
(3)	$\mid f_{1N} \mid / f_1$	0.137	0.681	0.681
(4)	$\mid r_{VL} / f_V \mid$	0.986	18.304	0.457
(5)	L / f_L	0.107	0.0836	0.0356
(6)	Δn	0.107581	0.08888	0.19724
(7)	$\Delta \nu$	34.9	16.52	7.65
(8)	$\mid f_2 \mid / f_1$	0.130	0.219	0.219
(9)	f_L / f_3	—	1.406	1.406
(10)	L_{1N} / f_1	0.195	0.291	0.291
(11)	$f_1 / (f_W \cdot Z)$	0.527	0.392	0.392
(12)	f_t / L_A	39.345	13.889	13.889
(13)	f_W / L_A	27.781	4.630	4.630

Figures 2 and 3 show spherical aberration, astigmatism, distortion, and horizontal aberration for the wide-angle end and telephoto end of Embodiment 1 respectively. Horizontal aberration (A) shows the situation when the anti-vibration lens group G_V is located on the optical axis. The horizontal aberration (B) shows the situation when vibration is corrected by moving the anti-vibration lens group G_V by ΔS in the direction substantially perpendicular to the optical axis. In the same manner, Figures 5 and 6 show various aberrations for the wide-angle end and telephoto end of Embodiment 2 respectively. Figures 8 and 9 show various aberrations for the wide-angle end and telephoto end of Embodiment 3 respectively. In each of the aberration diagrams, F_{NO} is the F-number and Y is the image height. In the astigmatism diagram, the solid line S indicates the sagittal image plane and the broken line M indicates the meridional image plane.

As is clear from all of the aberration diagrams, all of the embodiments of the present invention satisfactorily correct various aberrations at any focal length.

It is clear from the above that the apparatus incorporating the principles of the present invention provides a high-performance zoom lens having an anti-vibration function and a long focal length suitable for a camera for photography and videos.

Various modifications will become possible for those skilled in the art after receiving the teachings of the present disclosure without departing from the scope thereof.

What is claimed is:

1. An anti-vibration zoom lens comprising, in order from the object end:

a first lens group;

a second lens group having a negative refractive power; and

a last lens group arranged at the image side of said zoom lens, wherein

said first lens group includes a focusing lens group; and

said last lens group includes an anti-vibration lens group G_V; and wherein, said focusing lens group moves along the direction of the optical axis of said zoom lens during focusing;

at least said second lens group moves along the direction of said optical axis during zooming; and

said anti-vibration lens group moves in a direction substantially perpendicular to said optical axis during vibration correction.

2. A zoom lens, as claimed in claim 1, wherein

the distance between said first lens group and said second lens group increases during zooming from the wide-angle end to the telephoto end; and

the distance changes between said second lens group and said last lens group.

3. A zoom lens, as claimed in claim 1, wherein the following condition (1) is satisfied:

$$\Delta S / | f_L | < 0.1 \tag{1}$$

where:

ΔS is the maximum amount of displacement of said anti-vibration lens group in the direction substantially perpendicular to said optical axis during vibration correction; and

f_L is the focal length of said last lens group.

4. A zoom lens, as claimed in claim 2, wherein the following condition (1) is satisfied:

$$\Delta S / | f_L | < 0.1 \tag{1}$$

where:

ΔS is the maximum amount of displacement of said anti-vibration lens group in the direction substantially perpendicular to said optical axis during vibration correction; and

f_L is the focal length of said last lens group.

5. A zoom lens, as claimed in claim 1, wherein the following conditions (2) and (3) are satisfied:

$$0.2 < | f_V | / f_L < 10 \quad (2)$$

$$0.05 < | f_{1N} | / f_1 < 10 \quad (3)$$

where:

f_V is the focal length of said anti-vibration lens group;

f_L is the focal length of said last lens group;

f_{1N} is the focal length of said focusing lens group; and

f_1 is the focal length of said first lens group.

6. A zoom lens, as claimed in claim 2, wherein the following conditions (2) and (3) are satisfied:

$$0.2 < | f_V | / f_L < 10 \quad (2)$$

$$0.05 < | f_{1N} | / f_1 < 10 \quad (3)$$

where:

f_V is the focal length of said anti-vibration lens group;

f_L is the focal length of said last lens group;

f_{1N} is the focal length of said focusing lens group; and

f_1 is the focal length of said first lens group.

7. A zoom lens, as claimed in claim 1, wherein a third lens group having a positive refractive power is included between said second lens group and said last lens group.

8. A zoom lens, as claimed in claim 2, wherein a third lens group having a positive refractive power is included between said second lens group and said last lens group.

9. A zoom lens, as claimed in claim 3, wherein a third lens group having a positive refractive power is included between said second lens group and said last lens group.

10. A zoom lens, as claimed in claim 4, wherein a third lens group having a positive refractive power is included between said second lens group and said last lens group.

11. A zoom lens, as claimed in claim 7, wherein the distance between said third lens group and said last lens group changes during zooming.

12. A zoom lens, as claimed in claim 11, wherein said first lens group and said last lens group are fixed in the direction along said optical axis during zooming.

13. A zoom lens, as claimed in claim 1, wherein a fixed stop is arranged on said optical axis.

14. A zoom lens, as claimed in claim 2, wherein a fixed stop is arranged on said optical axis.

15. A zoom lens, as claimed in claim 3, wherein a fixed stop is arranged on said optical axis.

16. A zoom lens, as claimed in claim 4, wherein a fixed stop is arranged on said optical axis.

17. A zoom lens, as claimed in claim 5, wherein a fixed stop is arranged on said optical axis.

18. A zoom lens, as claimed in claim 6, wherein a fixed stop is arranged on said optical axis.

19. A zoom lens, as claimed in claim 7, wherein a fixed stop is arranged on said optical axis.

20. A zoom lens, as claimed in claim 1, wherein said first lens group has a positive refractive power, said second lens group has a negative refractive power, and said last lens group has a positive refractive power, said second lens group moves toward said image end during zooming from the wide-angle end to the telephoto end.

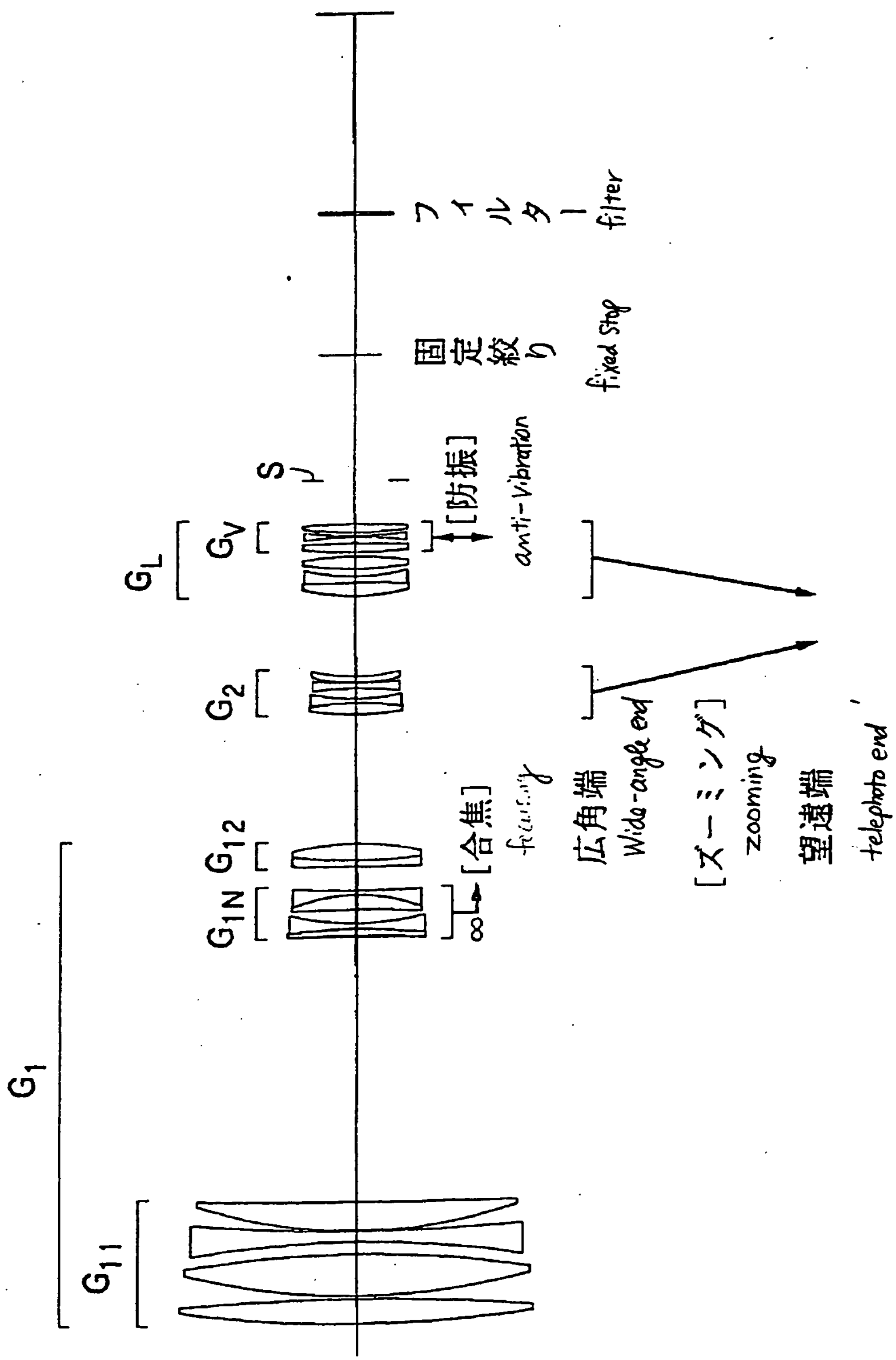
21. A zoom lens, as claimed in claim 1, wherein said first lens group includes a lens subgroup having a negative refractive power, said lens subgroup being adapted to move along said optical axis for focusing on objects at an intermediate distance.

ABSTRACT

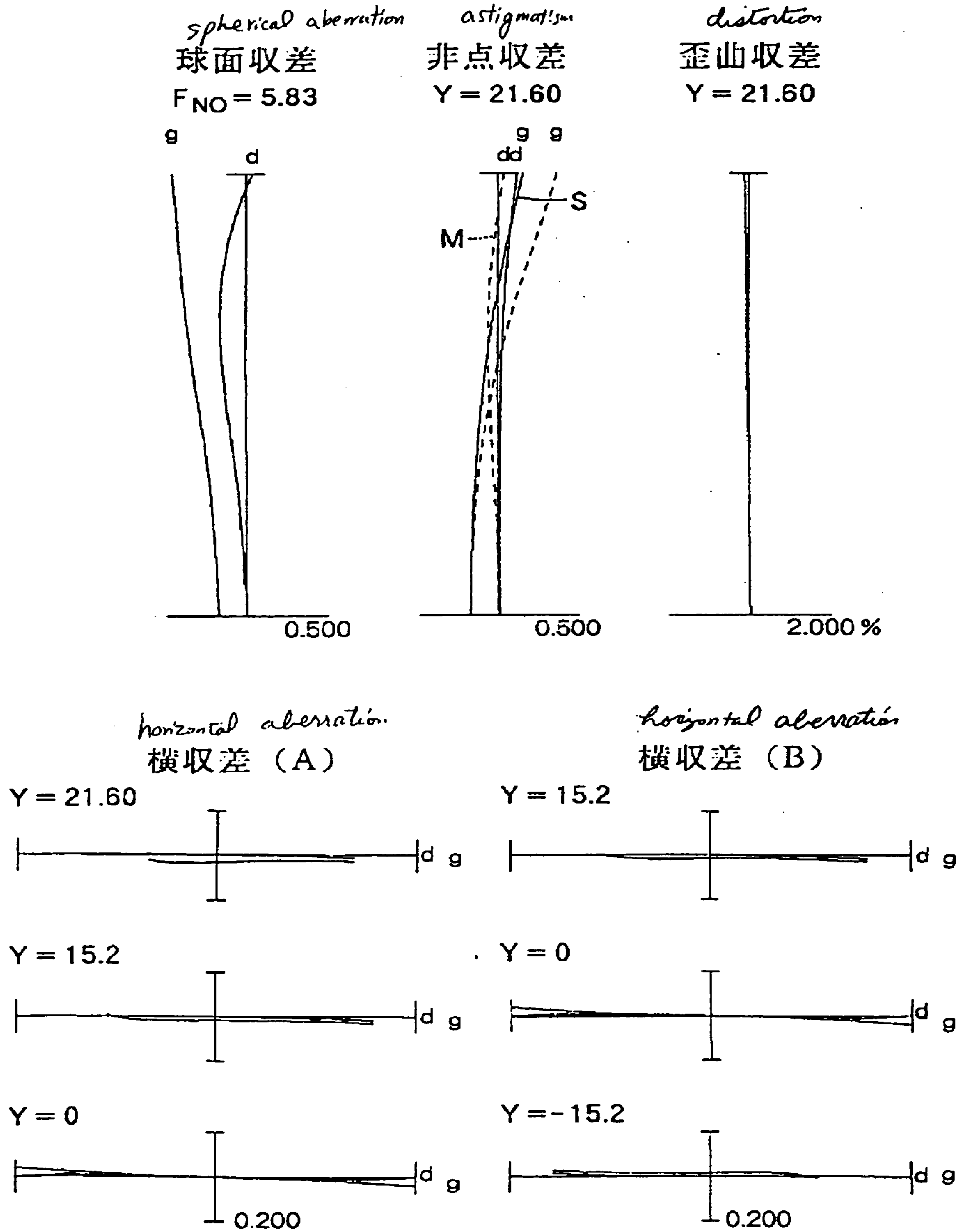
An anti-vibration zoom lens having, in order from the object end: a first lens group, a second lens group having a negative refractive power, and a last lens group arranged closest to the image end of the zoom lens. The first lens group includes a focusing lens group, and the last lens group includes an anti-vibration lens group wherein the focusing lens group moves along the direction of the optical axis of the zoom lens during focusing. At least the second lens group moves along the direction of the optical axis during zooming, and the anti-vibration lens group moves in a direction substantially perpendicular to the optical axis during vibration correction.

【書類名】図面

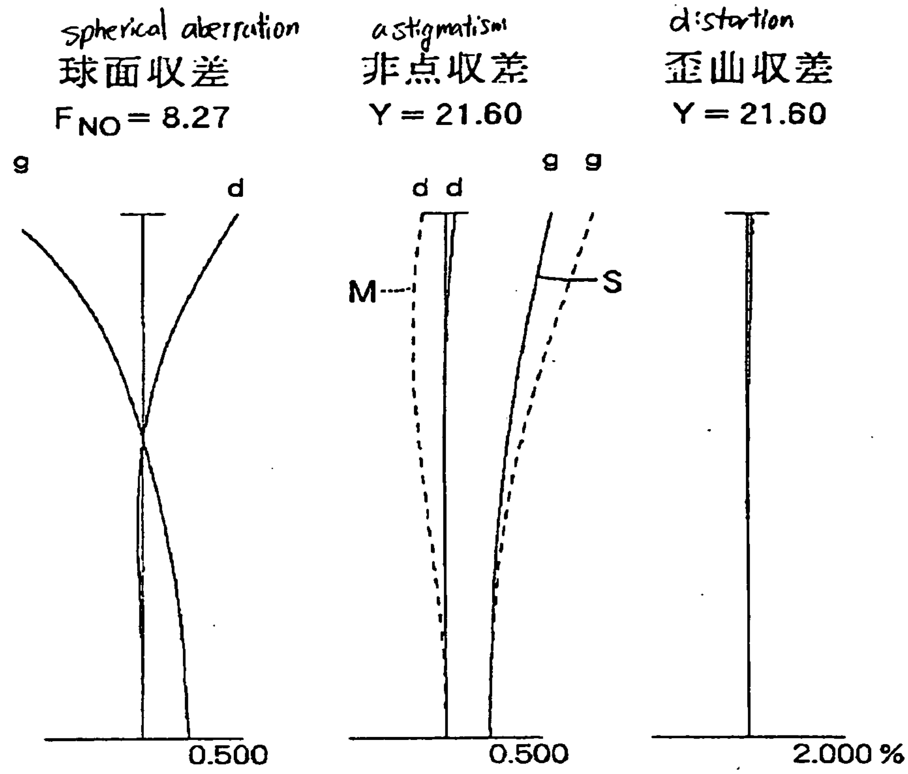
【図１】 Fig.1

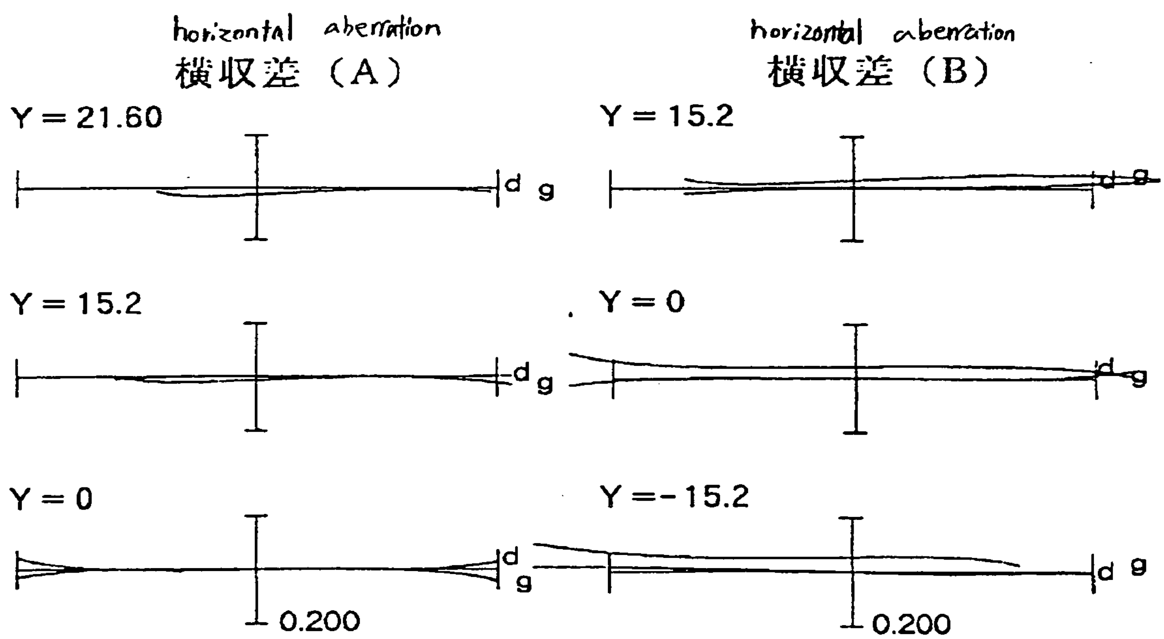


【図2】 Fig. 2　　WIDE-ANGLE END

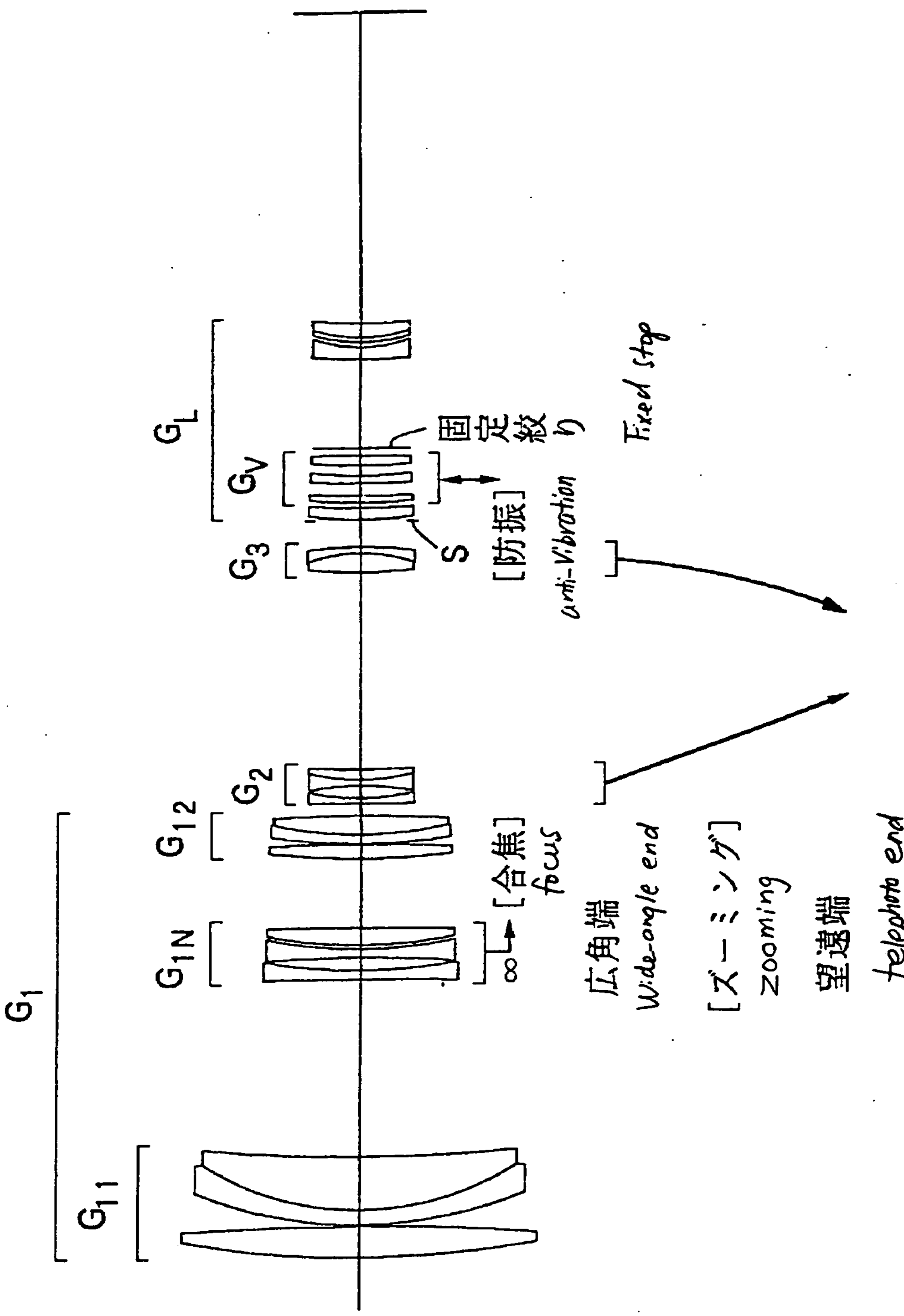


【図3】 Fig.3 TELEPHOTO END

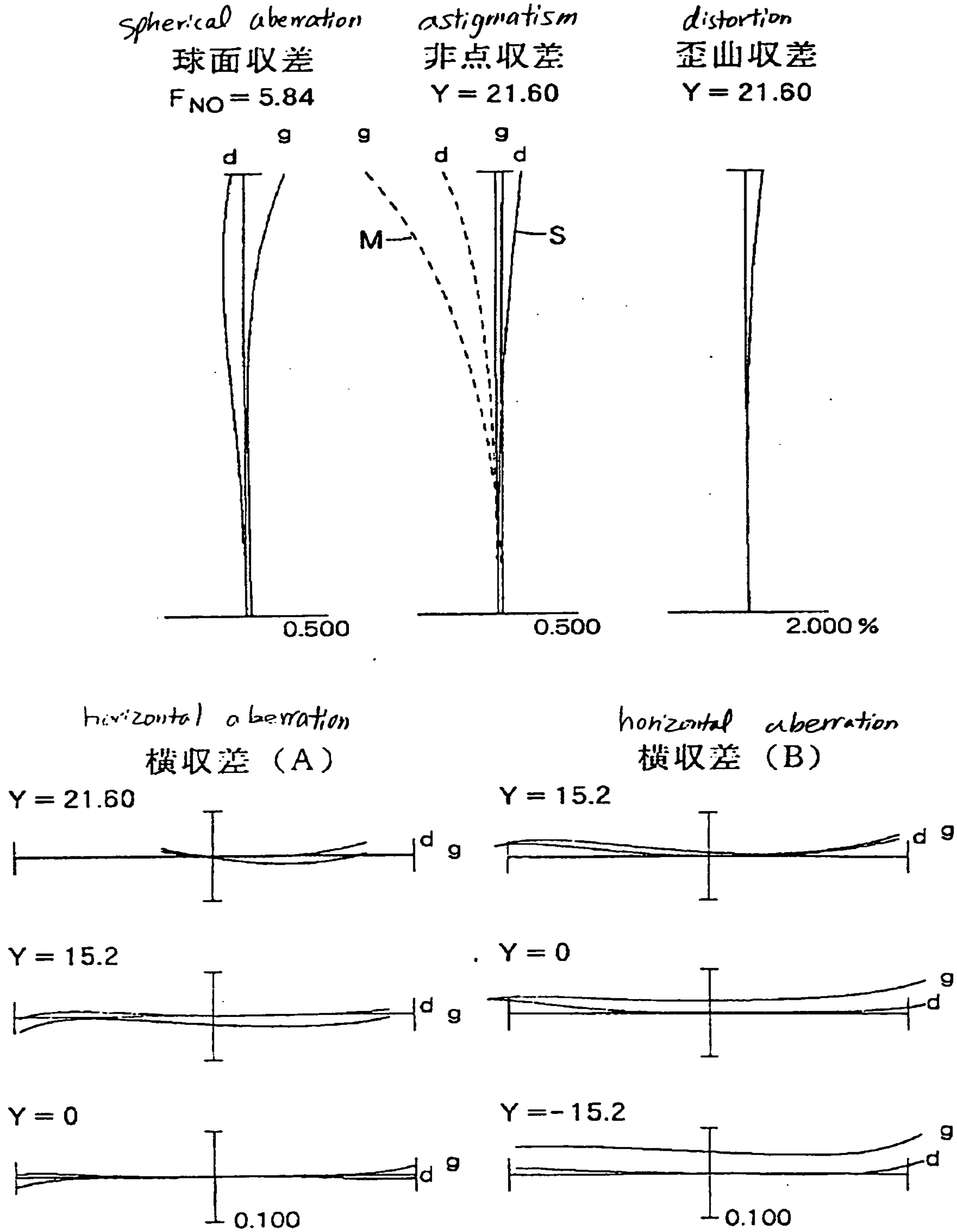




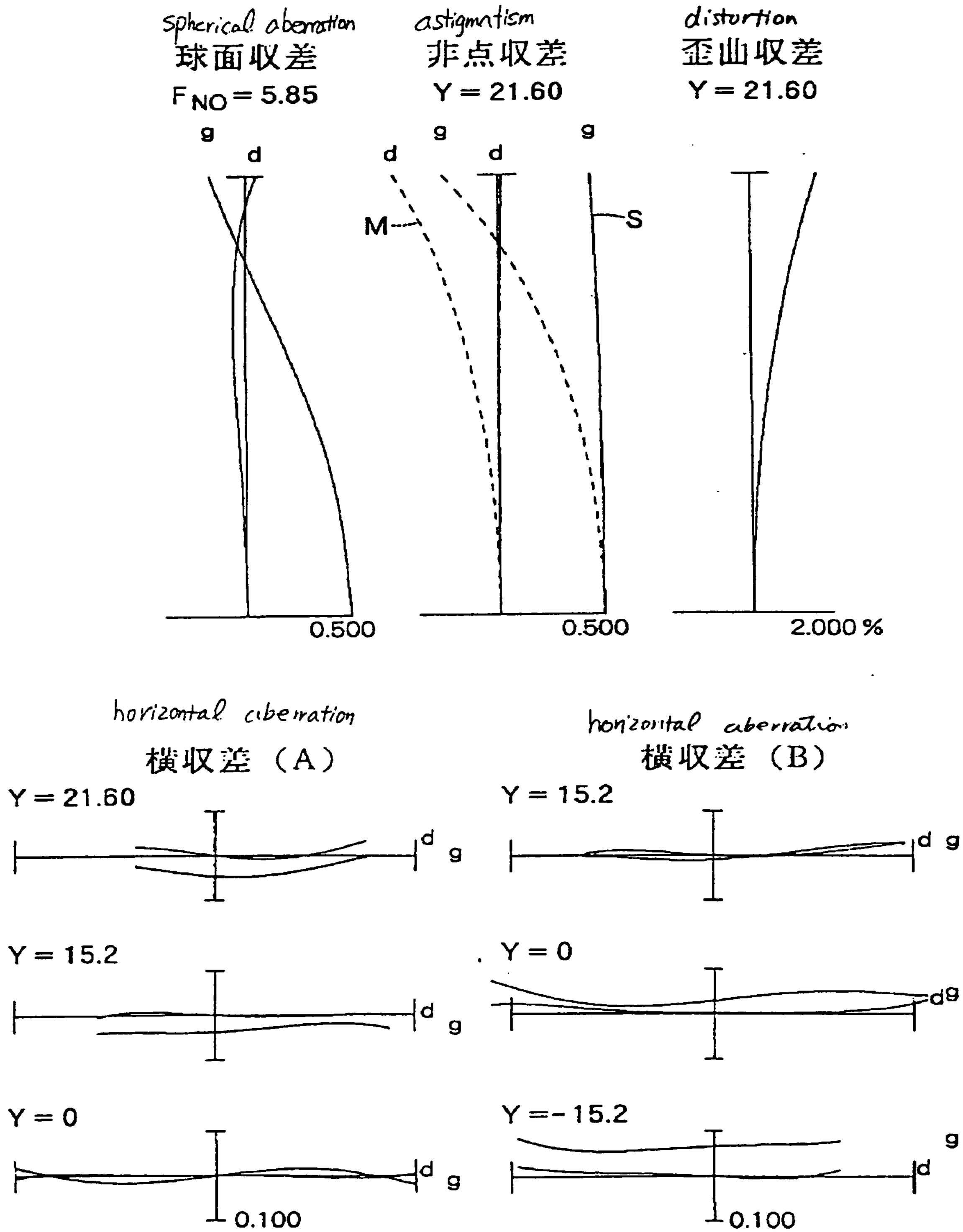
【図４】 Fig. 4


G1
G11
G1N
G12
G2
G3
GV
GL
S
固定絞り
Fixed stop
[防振]
anti-Vibration
[合焦]
focus
∞
広角端
Wide-angle end
[ズーミング]
zooming
望遠端
telephoto end

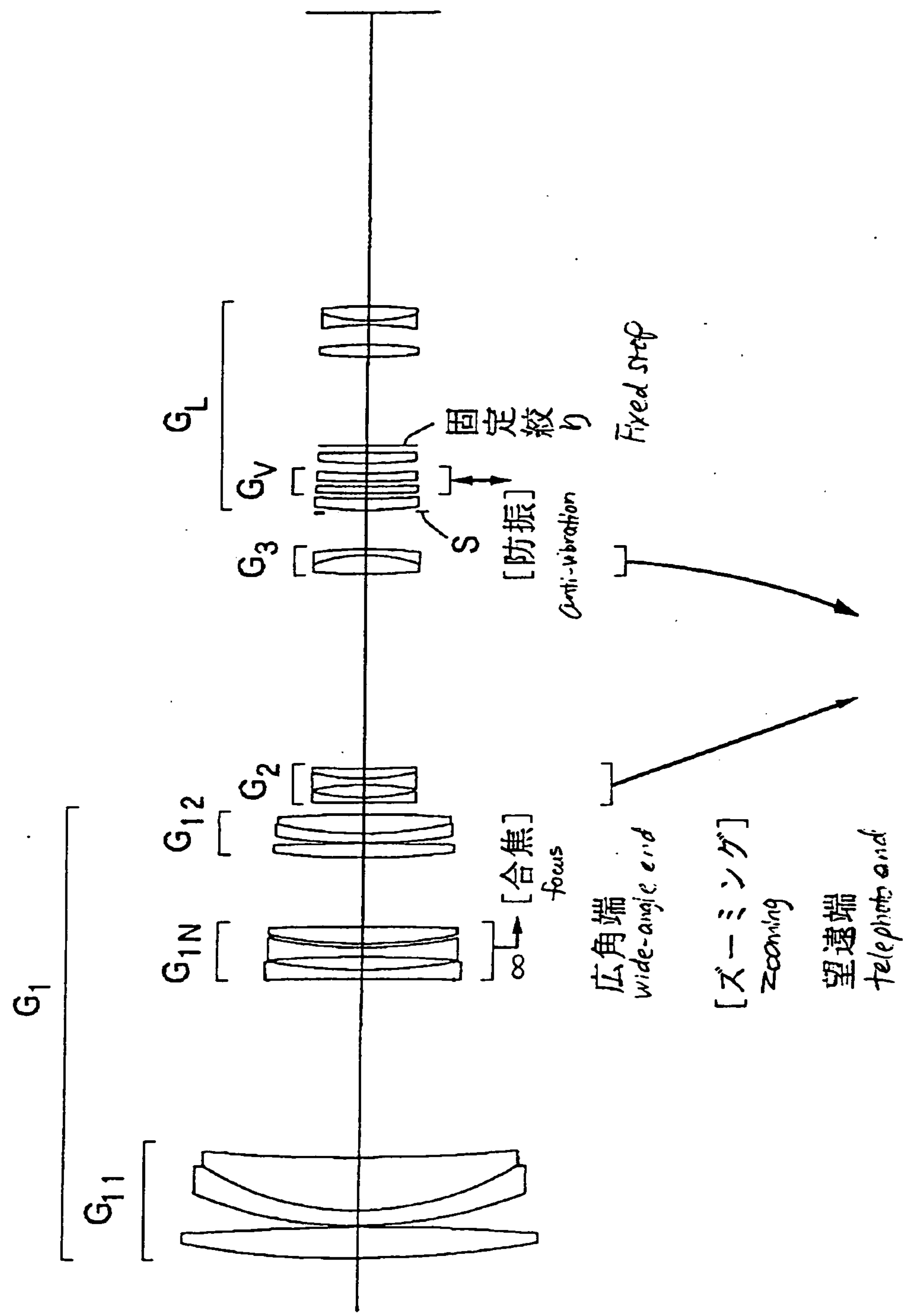
【図5】 Fig.5 WIDE-ANGLE END



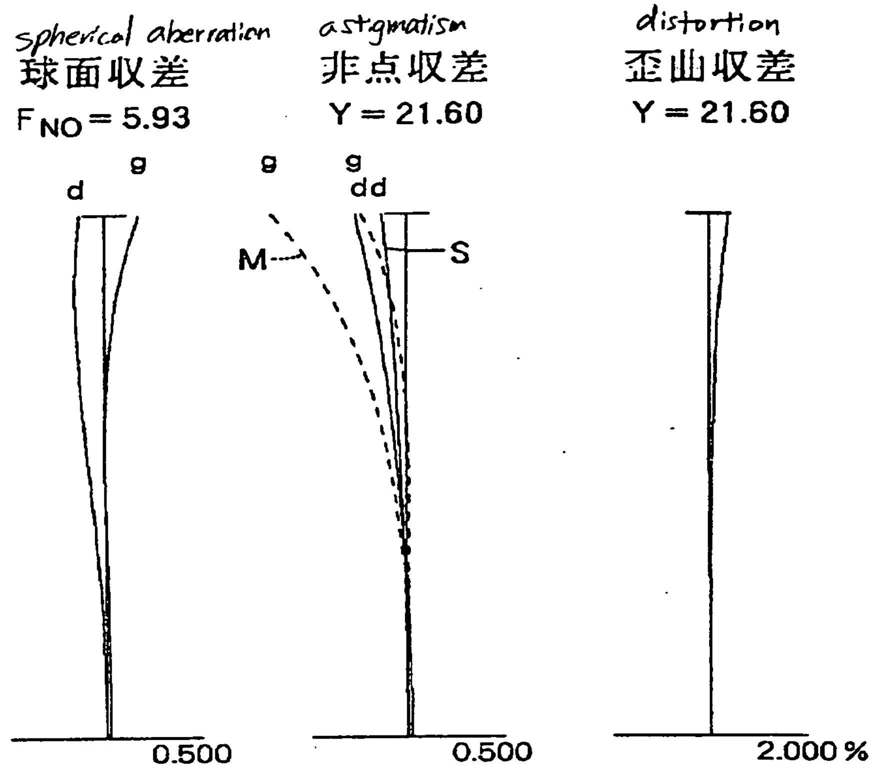
【図6】Fig. 6 TELEPHOTO END

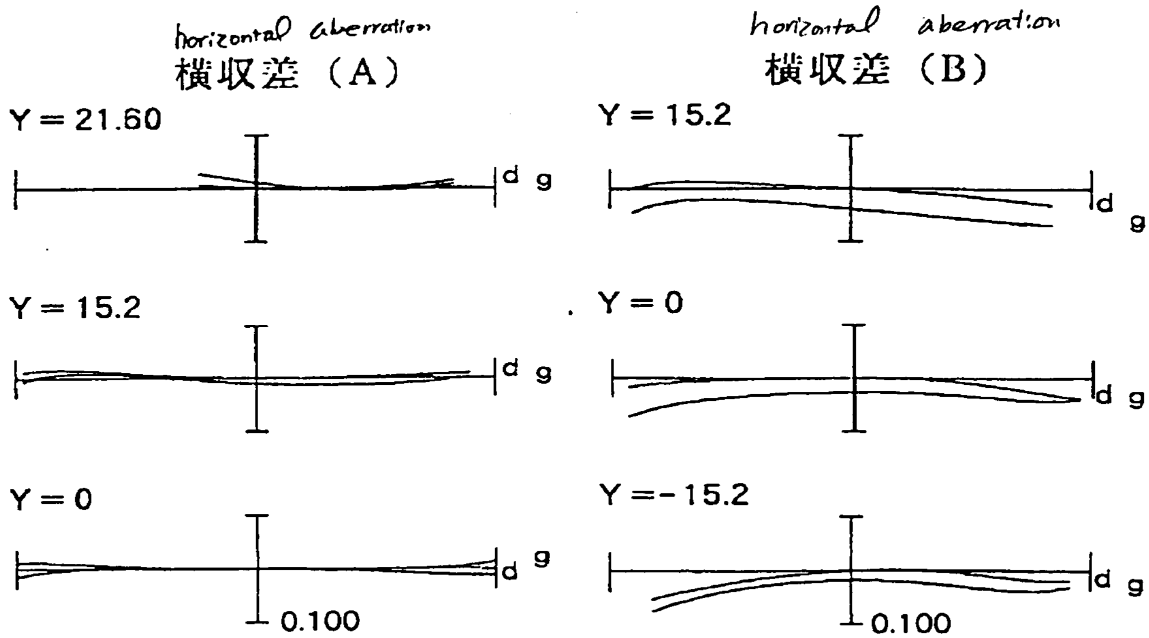


【図7】Fig. 7


G1
G11
G1N
G12
G2
G3
GV
GL
S
固定絞り
Fixed stop
[防振]
Anti-vibration
∞
[合焦]
focus
広角端
wide-angle end
[ズーミング]
zooming
望遠端
telephoto end

【図8】 Fig. 8 WIDE-ANGLE END





【図9】 Fig.9 TELEPHOTO END